IRRADIATION CREEP DAMAGE IN NUCLEAR REACTOR COMPONENTS

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The main mechanisms of failure in irradiated materials subjected to elevated temperature is mostly the result of the initiation, formation of voids, their coalescence and growth. The particle radiation in nuclear reactor components has crucial effect on the creep damage and final fracture. The flux of energetic particles significantly enhances particularly the creep process.

In order to investigate the irradiation creep problem the main processes that underlie the response of the irradiated material to stress are recognized. The processes of the defect formation and initial clustering as well as the interaction between point defects which are the basis of the creep theory are considered. The irradiation of metals by high energy particles leads to the interaction of energetic incident particles with lattice atoms [1]. The energetic particles transfer their kinetic energy to the lattice atoms creating primary knock on atom (PKA), which, in turn, leads to the displacement of next generation of target atoms, the process is called collision cascade. Collision cascade usually contains a vacancy-rich core surrounded by a halo of interstitial atoms. Displacement phase of the collision cascade usually lasts about 10^{-11} seconds, after about 10^{-10} seconds the cascade is thermalized. The pair of interstitial atom and vacancy in irradiated crystalline solids is known as the Frenkel defect. These phenomena such as Frenkel pairs formation are characteristic for irradiated materials and determine the physical effects, and with the application of stress, the mechanical effects of irradiation. These physical effects include numerous microstructural processes such as void formation growth, swelling, phase instability and radiation induced segregation [2]. After the end of the collisional phase of cascade evolution the point defects (vacancies and interstitials) may migrate in material leading to the formation of various forms of defect clusters: e.g. clusters of voids and helium bubbles. In this way, the process of damage initiation in the crystal structure is created.

Most of the energy deposited by high-energy particles is dissipated as the local heating of the crystal. Most of the Frenkel pairs created in collision cascade annihilate during the early phase of its evolution, the increase of the target temperature leads to additional recombination process of vacancies and interstitials at later stages. The origins of void swelling of metals are qualitatively understood. The collection of interstitial atoms as extra planes in the lattice causes the solid to swell. The consequences of radiation on material components structure include changes in shape and volume, increases in hardness, severe reduction in ductility and increased embrittlement, and susceptibility induced cracking.

The present work is concerned with the mechanical modeling of irradiation creep damage of metals applicable to structural analyses of metal components in nuclear reactor (Fig. 1). Multiscale model created to assess irradiation creep containing strong physical background related to the mechanism of generation of clusters of voids and helium bubbles in the irradiated solids has been built [3]. The irradiation creep was described by modifying Kachanov creep damage theory for brittle and Hoff creep damage theory for ductile materials by incorporating the effect of irradiation.

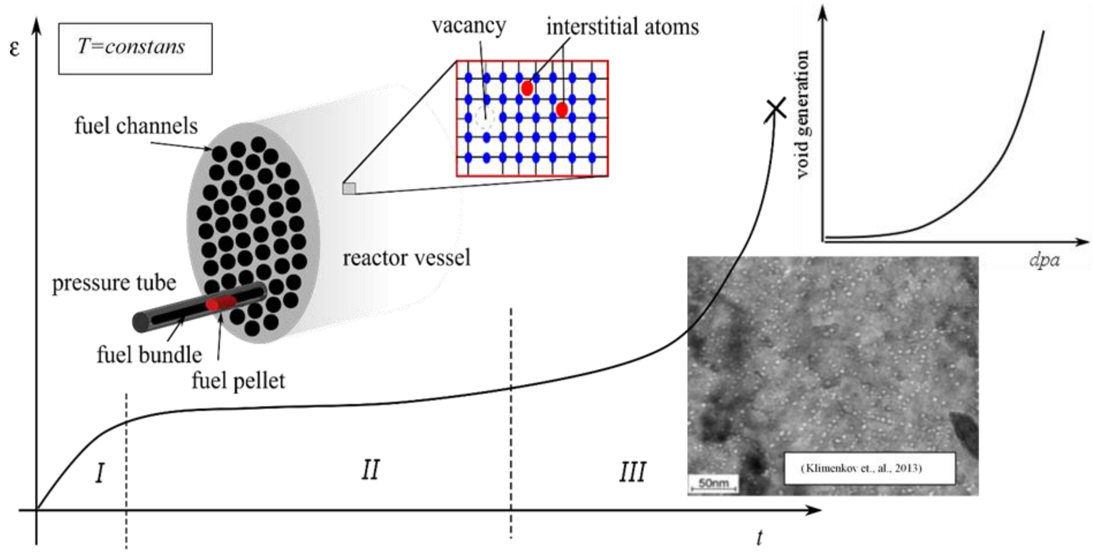

Fig. Degradation mechanisms of specific nuclear reactor structures

A bar tensioned with normal force constant in time serves as a model. It is assumed, that material is exposed in equal intervals of time to equal doses of irradiation. After each time interval, hence after accumulation of each irradiation burst, the sample is reanalyzed. Diminishing of effective cross-sectional area of the bar caused by particle flux is assumed relatively at the same level at each consecutive application of irradiation. However, at each emission of radiation (radiation burst) it acts on the cross section reduced, due to creep damage. All the irradiated creep process is thus divided into several steps. In a single cycle the material is subjected to flux of energetic particles (or irradiations pulses), which induce radiation defects in the material expressed in *dpa* [4]. Simultaneously, the material is subjected to thermo-mechanical loads at high temperature, which induce the deformation and cracking of material in creep range. The proposed model takes into account both; diminishing of the effective cross-sectional area caused by particle flux and geometrical changes resulting from creep deformation. At each emission of radiation it acts on the cross section reduced, due to creep damage. Consequently, the thermo-mechanical loads act on the cross section reduced due to radiation induced damage. In this way bilateral coupling of radiation and creep damage is performed.

As an application of the proposed equations, creep damage evolution in a metal component subjected to irradiation load was analyzed. The semi-analytical results and the special topics associated with irradiation creep modelling are discussed. The utility of the proposed constitutive equation was demonstrated by analyzing the irradiation creep and irradiation creep damage for different materials parameters. The experimental result confirm the mathematical analysis that the lifetime of irradiated components is significantly shorted [5].

References

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